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ISSN 0974-5904, Volume 08, No. 02

International Journal of Earth Sciences and Engineering

April 2015, P.P.120-125

Engineering Properties of Masonry Mortars with Gold Mine Tailings as Partial Substitute for Manufactured Sand

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Abstract: Sand constitutes bulk of cement mortar. Natural River sand is becoming scarce and meeting the requirement of fine aggregates for the construction industry is becoming a challenging task. The effect of replacing manufactured sand with gold mine tailings on the properties of masonry mortars such as workability, compressive strength, water retentivity and drying shrinkage is investigated. Manufactured sand is reconstituted by replacing with 10%, 20% and 30% gold mine tailings. Major findings of the study are: (a) there is a linear relationship between flow and water cement ratio of mortars. Flow increases with the increase in water cement ratio. (b) as the sand becomes finer mortar compressive strength decreases while drying shrinkage increases. (c) Water retentivity increases with increase in fineness of sand for all sand types.

Keywords: *Gold mine tailings; manufactured sand; workability; compressive strength; drying shrinkage*

1. Introduction

Indian construction industry is one of the largest in terms of volume of raw materials/natural resources consumed. The consumption of cement will increase by 166% by the end of the year 2020(1), which leads to large scale consumption of fine and coarse aggregates. The approximate annual consumption of fine aggregates in India is $350X10^9$ m^3 (2). It is a challenging task to meet the demand for fine aggregates without exploiting the natural resources. Thus, to sustain the demand for fine aggregates, it becomes imperative to explore the Possibility of utilizing alternative materials which are sustainable. Large quantity of industrial waste is unutilised for several decades. One of the studies indicate that about 20 million tonnes of inorganic waste is generated annually (3), which includes red mud, lime sludge, zinc tailings, gold mine tailings etc. In this investigation, an attempt is made to study the flow characteristics, compressive strength, water retentivity and drying shrinkage properties of masonry mortars with gold mine tailings as partial substitute for manufactured sand. Rock crushed to the required grain size distribution is called manufactured sand and it is extensively used as fine aggregate in construction industry.

2. Scope of the work and experimental programme

The main of the study is to characterize the properties of masonry mortar with gold mine tailings as a partial substitute for manufactured sand. The important characteristics such as workability, compressive strength, water retentivity and drying shrinkage are determined. The details of mortar proportions and various tests performed are given in Table 1. In order to minimise the errors arising in volume batching, the volumes of cement, manufactured sand and gold mine tailings are converted to weight ratios based on their loose bulk densities. These converted ratios are used in the experiments. Gold mine tailings are very fine particles, which contain about 72% Silica as SiO_2. The grain size distribution reveals that around 70% of the material is coarser than 75 microns. In order to study the effect of replacing manufactured sand with gold mine tailings, manufactured sand was replaced by gold mine tailings at three percentages (10%, 20% and 30%). The grain size distribution curves for the materials used in the investigation are shown in Figure 1.

The properties of mortar greatly depend on the water content of the mix. The mortars used for masonry construction will have a range of flow values that influence that workability of mortar. The flow values of masonry mortars in construction sites usually vary from 86% to 119% (4). A flow value of 100% is used to investigate the characteristics of mortars.

3. Materials used in the investigation

3.1. Cement

Ordinary Portland cement conforming to IS: 8112 (5) is used in the preparation of mortars.

Table 1*-Details of test programme for various mortars*

Mortar proportion (By volume)			Mortar flow (%)	Properties investigated				Mortar designation
C	MS	GMT		I	II	III	IV	
1	6	-	100	√	√	√	√	MS
1	-	6	100	√	√	√	√	GMT
1	(0.9)6	(0.1)6	100	√	-	√	√	RMS10
1	(0.8)6	(0.2)6	100	√	√	√	√	RMS20
1	(0.7)6	(0.3)6	100	√	√	√	√	RMS30

C: Cement, MS: Manufactured sand, GMT: Gold mine tailings
I: Flow characteristics, II: Compressive strength, III: Water retentivity, IV: Drying shrinkage

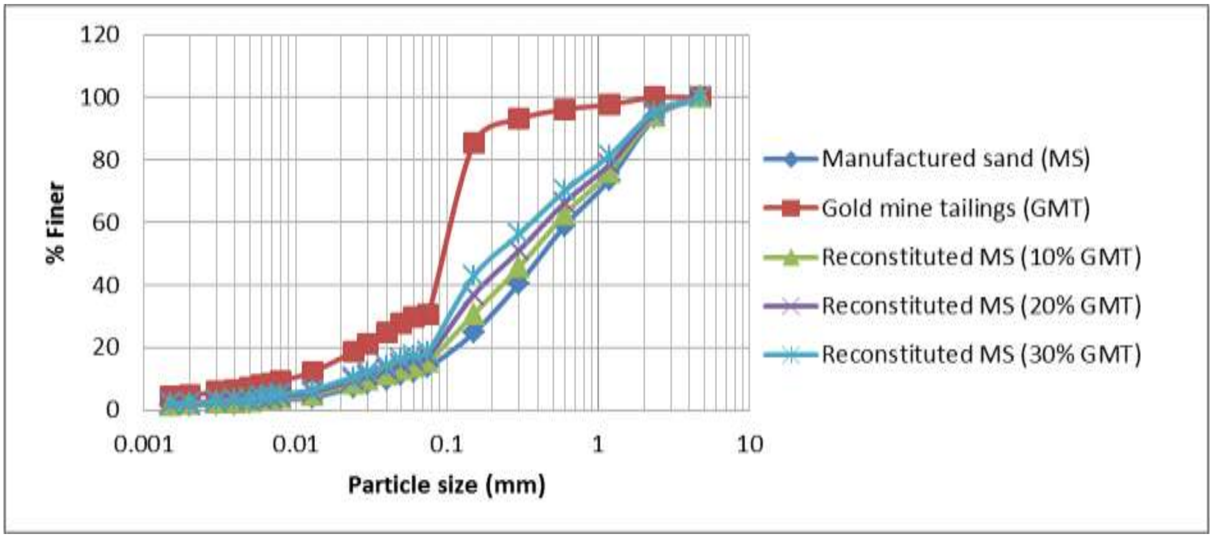

Figure 1 *Particle size distribution curves for manufactured sand, gold mine tailings and reconstituted manufactured sand*

3.2. Manufactured sand

The rocks are crushed to the required grain size distribution, which is called as manufactured sand. The sand used in this investigation was obtained from one of the plants situated near to Bangalore, India.

3.3. Gold Mine Tailings

Tailings are one of the primary waste products of mining operations. They are made of fine grained particles of the parent rock from which the ore is extracted. The characteristics of tailings depend upon the composition of the parent rock.

The tailings used in this investigation were obtained from Hutti gold mines, Hutti village, Raichur district, Karnataka, India. Chemical composition of the tailings was evaluated and is shown in Table 2.

4. Testing Procedure

4.1. Determination of Workability of Mortars through Flow Tests

The mortar should possess sufficient workability so that the mason can spread it easily and also adhere well to the masonry units. The composition of the mix and water cement ratio affects the workability. Workability of mortar is generally characterized by conducting tests given in various standard codes of practice like Dropping ball test (6), Cone penetration test (7) and slump test (8). In this investigation, workability characteristics are measured using flow table test. Using flow table test the flow values of cement mortar containing manufactured sand, gold mine tailings and reconstituted manufactured sand can be easily determined with the water cement ratios having a very wide range of flow values. BS: 4551 (6) guidelines are followed to carry out experiments to determine the flow of mortars.

4.2. Compressive Strength of Mortar

Compressive strength of mortar was obtained by testing 50 mm size cube specimens as specified in IS: 2250-1990 (7).

Mortar is thoroughly mixed and filled into a metal mould in three layers, each layer is tamped twenty five times using a standard tamping rod.The mortar cubes prepared in this manner are removed from the moulds after twenty four hours of casting. The mortar cubes are tested for compressive strength in a compression testing machine after 7, 28 and 56 days of curing. The mean of three cubes tested is reported as compressive strength of mortar.

4.3. Water Retentivity

Water retentivity is defined as the ability of the fresh mortar to hold/retain water when placed in contact with absorbent masonry units. Mix proportion, water cement ratio, type of cementitious binder etc, are some of the factors that affect water retentivity. Standard codes of practice such as IS: 2250 (7), ASTM C 91 (9) and BS: 4551 (6) give procedures to determine water retentivity of mortars. In this investigation, water retentivity is determined by adopting BS: 4551 (6) code guidelines.

4.4. Drying Shrinkage

The drying shrinkage of mortar is determined by following the procedure given in ASTM C 1148-92a (10). The drying shrinkage as found by this method is a measure of decrease in length of test specimen in unrestrained condition, under drying condition, after an initial period of curing. The average of five mortar specimens is reported as drying shrinkage value of mortar as specified in ASTM C 1148 92a (10).

***Table 2**- Chemical composition of gold mine tailings*

Parameters	Result (%)	Parameters	Result (%)
Loss on ignition	1.08	Manganese as MnO	0.077
Calcium as CaO	6.10	Zinc as ZnO	0.011
Magnesium as MgO	3.68	Nickel as NiO	0.006
Iron as Fe_2O_3	6.70	Chromium as Cr_2O_3	0.008
Aluminium as Al_2O_3	3.85	Lead as PbO	0.007
Sodium as Na_2O	0.078	Silica as SiO_2	71.6
Potassium as K_2O	0.285	Chloride as CL^-	0.070
Copper as CuO	0.010	Manganese as MnO	0.077

5. Results and Discussion

5.1. Flow Characteristics of Mortars

For a set of selected flow values, variation in water cement ratio and water content for mortars prepared with different sand types is shown in Table 3.

The flow value versus water cement ratio and total water content of the mortar mix prepared with five different sand types are shown in Figures 2 to 5. The following observations can be made from the results shown in Table 3 and Figures 2 to 5.

a) Flow increases with the increase in water cement ratio or water content for all the mortar mixes. There is a linear relationship between flow value and water cement ratio or water content of the mortar mix. The flow is very sensitive to water cement ratio or water content of the mix. In the case mortar prepared with manufactured sand, there is almost two fold increase in flow value for about 17% increase in water cement ratio or total water content of the mix. When gold mine tailings are blended with manufactured sand, the flow value increases by three and a half to four times for about 23% increase in water cement ratio or total water content of the mix.

b) Mortar with gold mine tailings requires more water to attain similar flow values when compared to mortars with manufactured sand and reconstituted manufactured sand. This may be attributed to the fact that fine sand has large surface area.

***Table 3**-Flow values, water-cement ratio and water content for sand types*

Sand Type	Flow values (%)							
	60		80		100		120	
	W/C	WC	W/C	WC	W/C	WC	W/C	WC
MS	1.17	14.88	1.25	15.88	1.33	16.89	1.41	17.89
GMT	2.06	26.78	2.27	29.42	2.48	32.06	2.69	34.71
RMS10	1.36	17.54	1.42	18.34	1.48	19.14	1.55	19.95
RMS20	1.39	18.26	1.46	19.10	1.52	19.94	1.59	20.78
RMS30	1.48	19.69	1.55	20.55	1.61	21.41	1.67	22.27

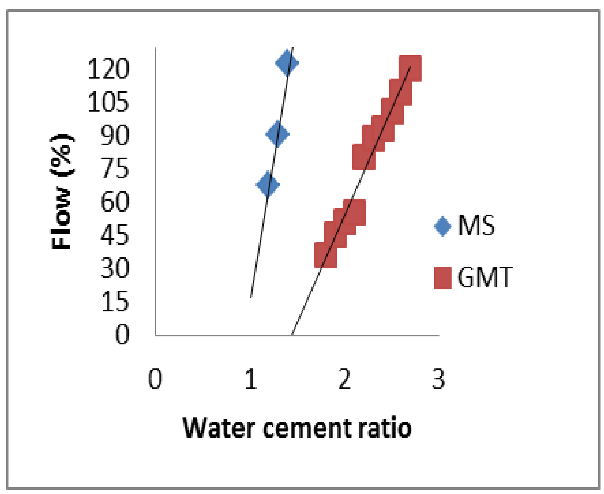

***Figure 2** Flow versus water cement ratio for manufactured sand and gold mine tailings*

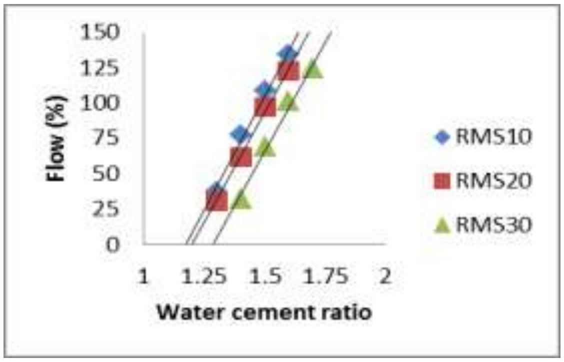

Figure 3 *Flow versus water cement ratio for reconstituted sands*

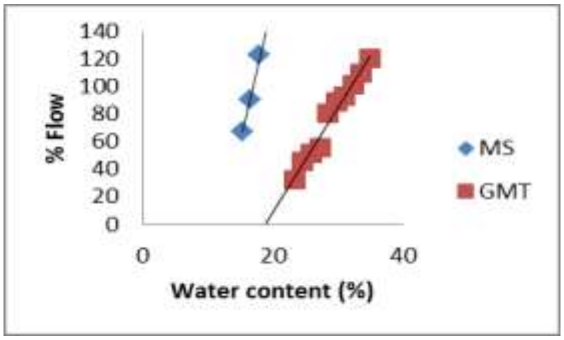

Figure 4 *Flow versus total water content for manufactured sand and gold mine tailings*

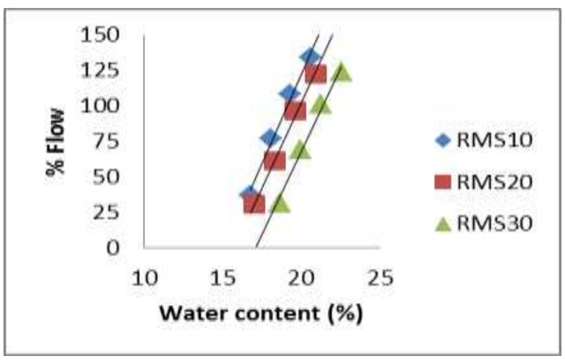

Figure 5 *Flow versus total water content for reconstituted sands*

5.2. Compressive Strength and Water Retentivity

Results of compressive strength, dry density and water retentivity of various mortar proportions are given in Table 4. The variation in compressive strength with age is shown in Figure 6. The following points emerge from the results given in Table 4 and Figure 6.

a) Water cement ratio increases as the fineness of sand increases in order to maintain 100% flow, for all the sand types.

b) Increase in water cement ratio leads to decrease in dry density of the mortar and hence reduction in mortar strength with increase in fineness of sand.

c) The compressive strength of cement mortar with manufactured sand as fine aggregates is 8.53 MPa. When manufactured sand is reconstituted with 20% and 30% gold mine tailings, the compressive strength decreases by 23% and 34% respectively. This can be attributed to the increase in fineness and also due to increase in water cement ratio.

d) To explore the possibility of increase in compressive strength beyond 28 days, the cubes were tested after 56 days of curing. The compressive strength increased by 7.5% in case of cement mortar containing gold mine tailings. Where as in case of cement mortar containing manufactured sand, the compressive strength increases by 30%. When manufactured sand is reconstituted with 20% and 30% gold mine tailings, the increase in compressive strength is 33% and 26% respectively. This increase in compressive strength may be attributed to the presence of CaO in gold mine tailings which contributes to the hydration of cement.

e) The water retentivity of cement mortar with gold mine tailings and manufactured sand is 88.3% and 78.9% respectively. The water retentivity increases as the fineness of sand increases. There is a marginal increase (6% to 7%) in water retentivity when manufactured sand is reconstituted with 10%, 20% and 30% gold mine tailings.

Table 4- *compressive strength and water retentivity for different sand types*

Mortar type	Flow of mortar (%)	Water cement ratio	Dry density (gm/cm^3)	Compressive strength (MPa)			Water retentivity (%)
				σ 7	σ 28	σ 56	
MS	100	1.33	2.26	3.07	8.53	11.07	78.9
GMT	100	2.48	1.92	0.67	3.47	3.73	88.3
RMS10	100	1.48	-	-	-	-	83.6
RMS20	100	1.52	2.18	2.80	6.53	8.67	83.5
RMS30	100	1.61	2.19	2.27	5.60	7.07	84.6

5.3. Drying shrinkage

Shrinkage that takes place during hardening of the mortar is called drying shrinkage and most of it takes place in the first few months. The drying shrinkage of mortar depends on various factors such as water cement ratio, water content, sand grading etc. In masonry construction, drying shrinkage causes shrinkage cracks observed at the masonry unit-mortar interface (11, 12). The drying shrinkage of mortar was tested in the laboratory through a mortar prism 250X25X25mm in unrestrained condition.

This differs from the actual drying shrinkage experienced in masonry construction. Thus drying shrinkage value of the mortar examined in the laboratory is more useful for comparative purposes. The variation in drying shrinkage with duration of drying for cement mortar made with different sand types is shown in Table 5 and Figures 7 and 8.

The following points emerge from the results on drying shrinkage

a) The drying shrinkage of mortars increase with the duration of drying.

b) The fineness of sand in mortars greatly affects the ultimate drying shrinkage values. There is an increase in drying shrinkage value when the sand becomes finer.

c) c) The ultimate drying shrinkage of cement mortar with gold mine tailings increases by 56% when compared with that of cement mortar with manufactured sand.

d) The ultimate drying shrinkage of reconstituted sand with 10% and 30% gold mine tailings increases by 42% and 62% respectively in comparison with cement mortar containing manufactured sand.

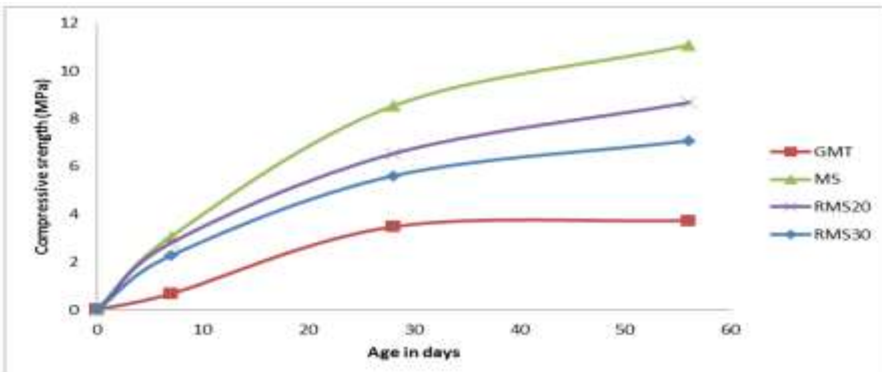

Figure 6 *Compressive strength versus age for different sand types*

Table 5 – *Drying shrinkage values for mortars*

Mortar type	1st day	4th day	11th day	18th day	25th day
MS	0	0.013	0.032	0.052	0.069
GMT	0	0.023	0.041	0.071	0.108
RMS10	0	0.017	0.045	0.064	0.098
RMS20	0	0.016	0.052	0.081	0.094
RMS30	0	0.019	0.067	0.081	0.112

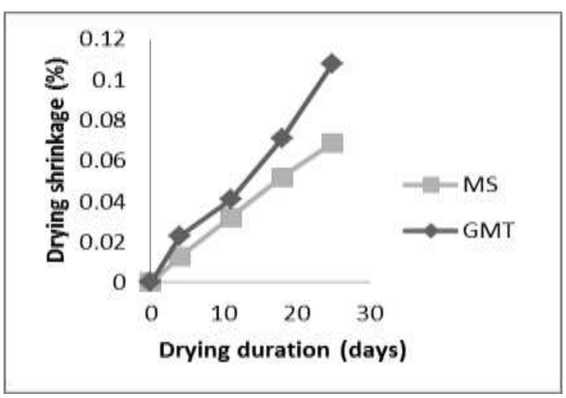

Figure 7 *Variation in drying shrinkage with drying duration for manufactured sand and gold mine Tailings*

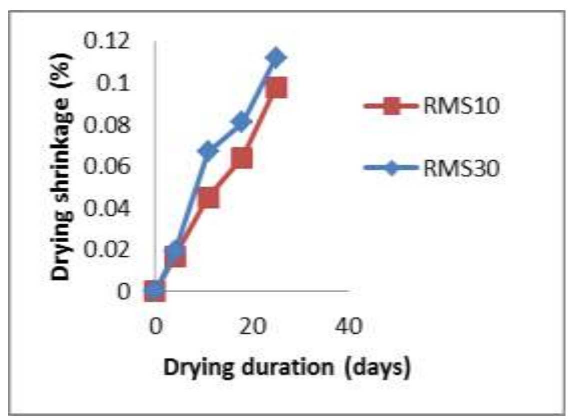

Figure 8 *Variation in drying shrinkage with drying duration for reconstituted sands*

6. Summary and Conclusions

Influence of the presence of gold mine tailings as a partial substitute for manufactured sand in cement mortar on the properties such as workability, compressive strength, water retentivity and drying shrinkage of mortar was investigated. The following conclusions can be drawn from the investigation.

a) Flow increases with increase in water cement ratio and water content of the mortar. There is a linear relationship between flow and water cement ratio as well as total water content of the mortar. To achieve 100% flow, reconstituted manufactured sand requires 13-27% excess water.
b) The compressive strength of cement mortar with gold mine tailings is more sensitive to the fineness of sand when compared to cement mortar with manufactured sand. The compressive strength of reconstituted manufactured sand with 20% and 30% gold mine tailings decreases by 23% and 34% respectively.
c) Water retentivity increases with increase in fineness of sand for all sand types.
d) Fineness of sand greatly affects the drying shrinkage values. The ultimate drying shrinkage values vary from 0.069% to 0.112%

Acknowledgment

The corresponding author thanks the management and Principal of Bangalore Technological Institute, Bangalore for permitting to carry out research work at SRM University, Kattankulathur. The author also thanks the management of SRM University, Kattankulathur, for providing research facilities.

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